Rupture directivities of small- and moderate-sized earthquakes in the Yamagata-Fukushima swarm triggered by the fluid migration after the 2011 Tohoku-Oki earthquake

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Earthquake nucleation and rupture propagation are strongly controlled by the distributions of stress and frictional strength on fault. It, however, is generally difficult to know the distribution of stress and friction on faults. In this study, we investigated the relationship of the rupture directivity with the frictional strength on the fault by analyzing waveform records in an earthquake swarm in central Tohoku (Fig. 1), which was triggered by the reduction in frictional strength due to the upward fluid movement after the 2011 Tohoku-Oki earthquake (Yoshida et al., 2016 and 2017, JGR; Yoshida & Hasegawa, 2018, JGR).

We utilized the dense nationwide seismic network in Japan to estimate the rupture directivity of small- and moderate-size earthquakes (M > 2). Source time functions were computed for each station based on the waveform deconvolution technique (Ligorría and Ammon, 1999) for 141 earthquakes by using nearby (< 300 m) small earthquakes as reference to remove the propagation- and site-effect. We found clear directional dependences of the peak amplitude and the pulse width in the apparent source time functions for most earthquakes, suggesting the earthquake rupture directivity (Fig. 2). By assuming the unilateral rupture model (Ben-Menahem 1961), we estimated the rupture direction, the rupture duration, and the rupture velocity for each earthquake.

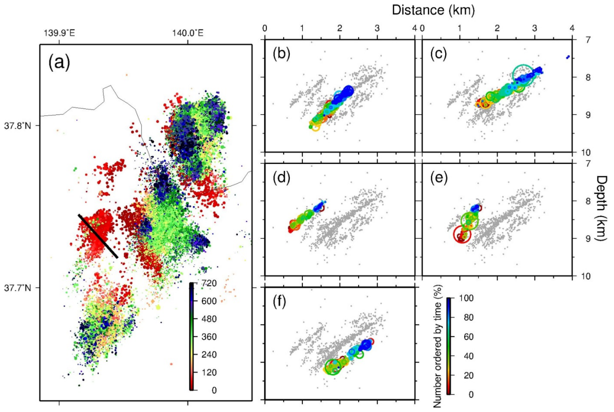

Figure 1 Spatio-temporal distribution of hypocenters in the Yamagata-Fukushima swarm.

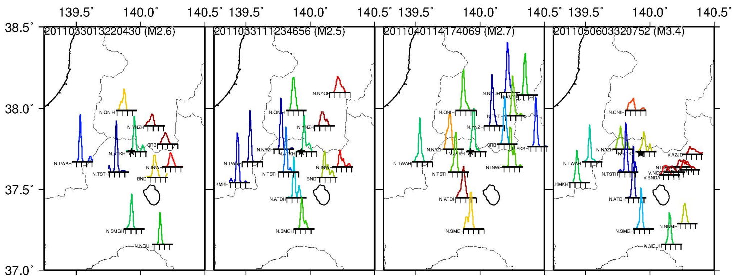

Figure 2 Examples of the directional dependency of the apparent source time function for four earthquakes.

The rupture directions are generally consistent with the macroscopic alignments of hypocenters (Fig. 1) and one of the nodal planes of focal mechanisms. On the other hand, the rupture direction of each earthquake is generally different from those of the hypocenter migration caused by the pore pressure diffusion along the fault. A similar observation that the rupture direction of each earthquake is different from the direction of the pore pressure diffusion was also reported in a case of induced seismicity cause by an active fluid injection experiment (Folesky et al., 2016). The discrepancy between the directions of microscopic and macroscopic propagations of the rupture can be explained by the spatial variation of the frictional strength. Since the frictional strength is higher ahead of the pore-pressure front (shallower part) than behind (deeper part), the rupture of each earthquake is difficult to develop toward shallower part.